U.S. DEPARTMENT OF ENERGY | Nuclear Energy

New Methods and Tools to Perform Safety Analysis within RISMC

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Outline

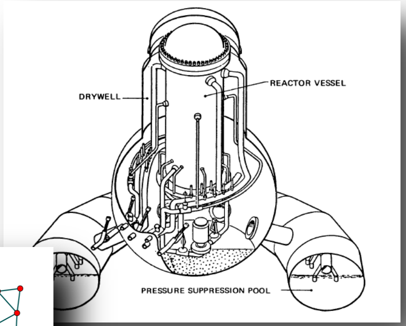
Four Major Parts/Steps:

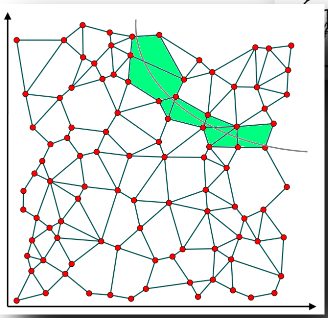
1. *Modeling (RELAP)*

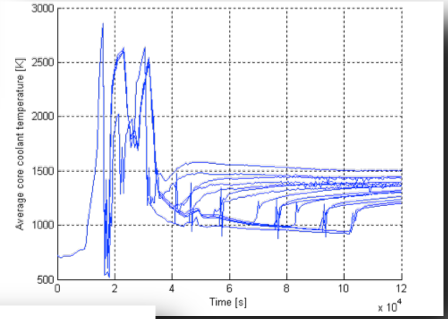
2. *Generate data*
   - *Adaptive sampling*
   - *Reduced order models*
   - *System emulators*

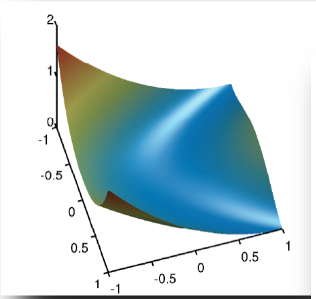
3. *Analyze time dependent data*
   - *Clustering*
   - *Symbolic conversion*

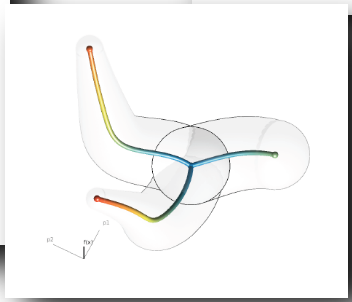
4. *Visualize data*
   - *Topology based*











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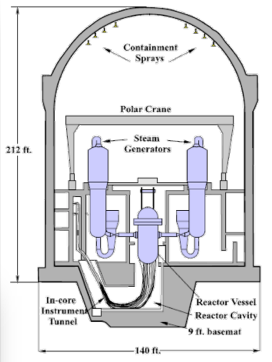
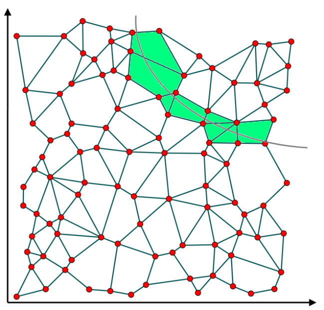
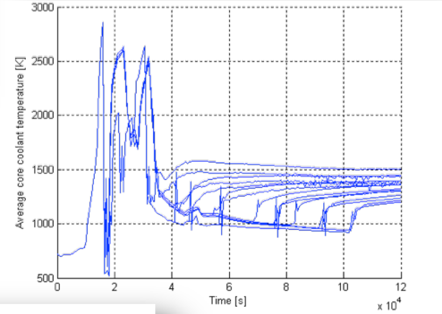
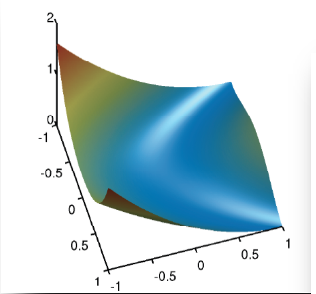
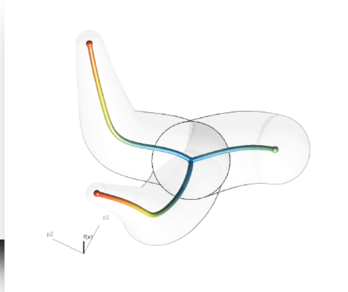










Data Generation

- **PRA applications**
  - Determine: $p_{failure} = \int_{\Omega} pdf(\omega)\,d\omega$

- **Strategies:**

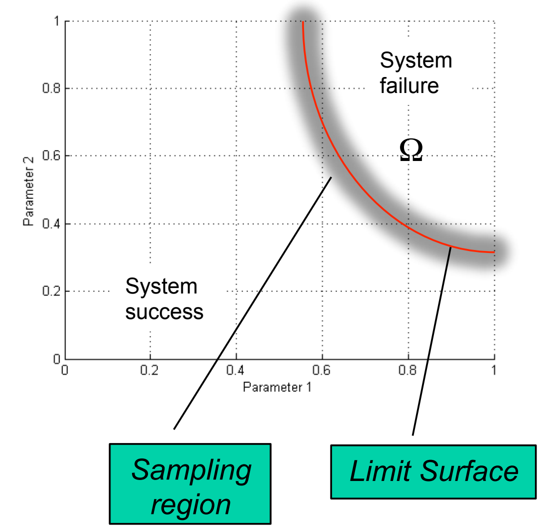
1. Calculate the integral directly

   - *Monte-Carlo (MC):*
     1. *Sample timing of events*
     2. *Run a single simulation*
     3. *Repeat 1. and 2. N times*

   - *Dynamic Event Trees (DETs):*
     - *Branch Scheduler*
     - *System Simulator*

   Branching occurs when particular conditions have been reached
   - *Value of specific variables*
   - *Specific time instants*
   - *Plant status*

2. Evaluate only boundaries of Ω
   - *Estimate boundaries*
   - *Concentrate samples around such boundaries*



Data Generation

For large systems, several problems arise if MC or DET are used:

- *The set of uncertain parameters is very large*
- *The computational costs are very high*
- *Many regions of the input space are not of interest*

The space of the possible solutions can be sampled only very sparsely

This precludes the ability to fully analyze the impact of uncertainties on the system dynamics

Understanding of a system depends heavily on where we query

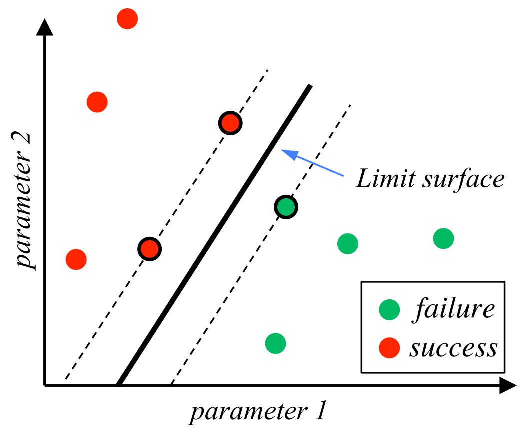
The scope of adaptive sampling is to identify the:

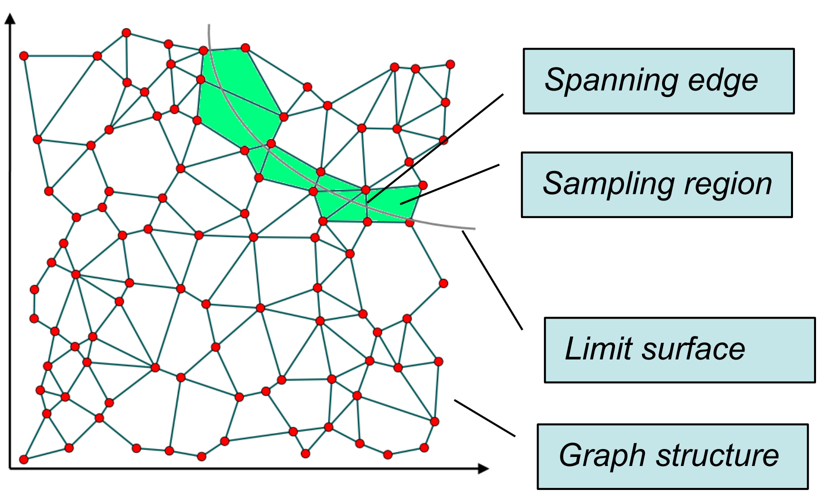
- *Set of relevant parameters*
- *Regions that are of interest for the user*

Performed by iteratively guiding the choice of the next sample by analyzing the previous sampling history

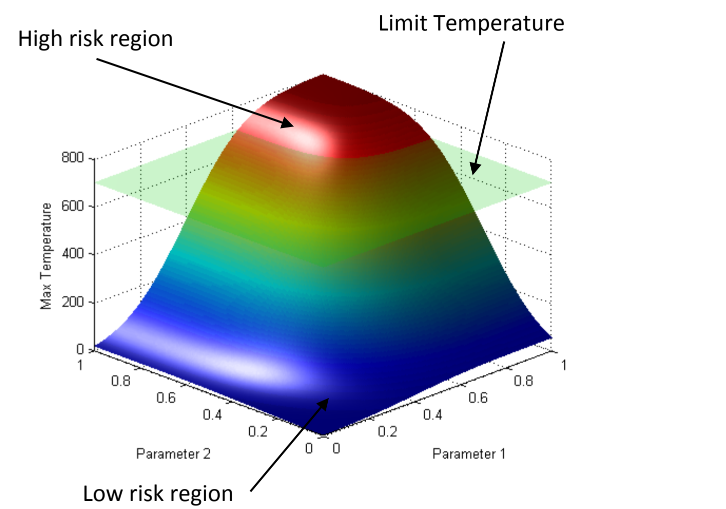
Adaptive Sampling

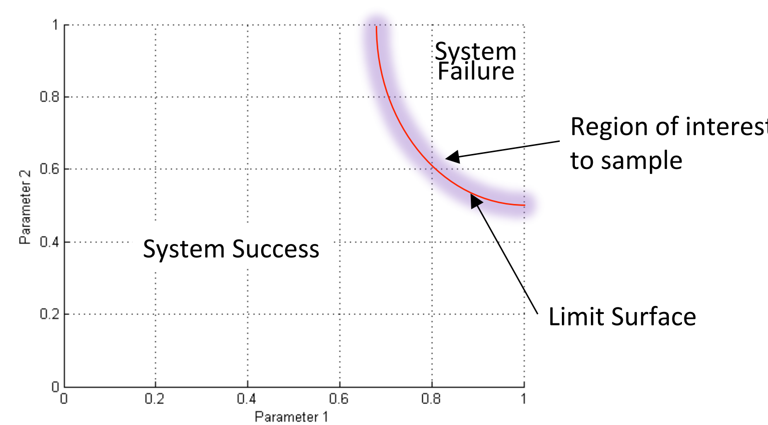
1- ***Data Driven***: *Geometric determination of the limit surface*





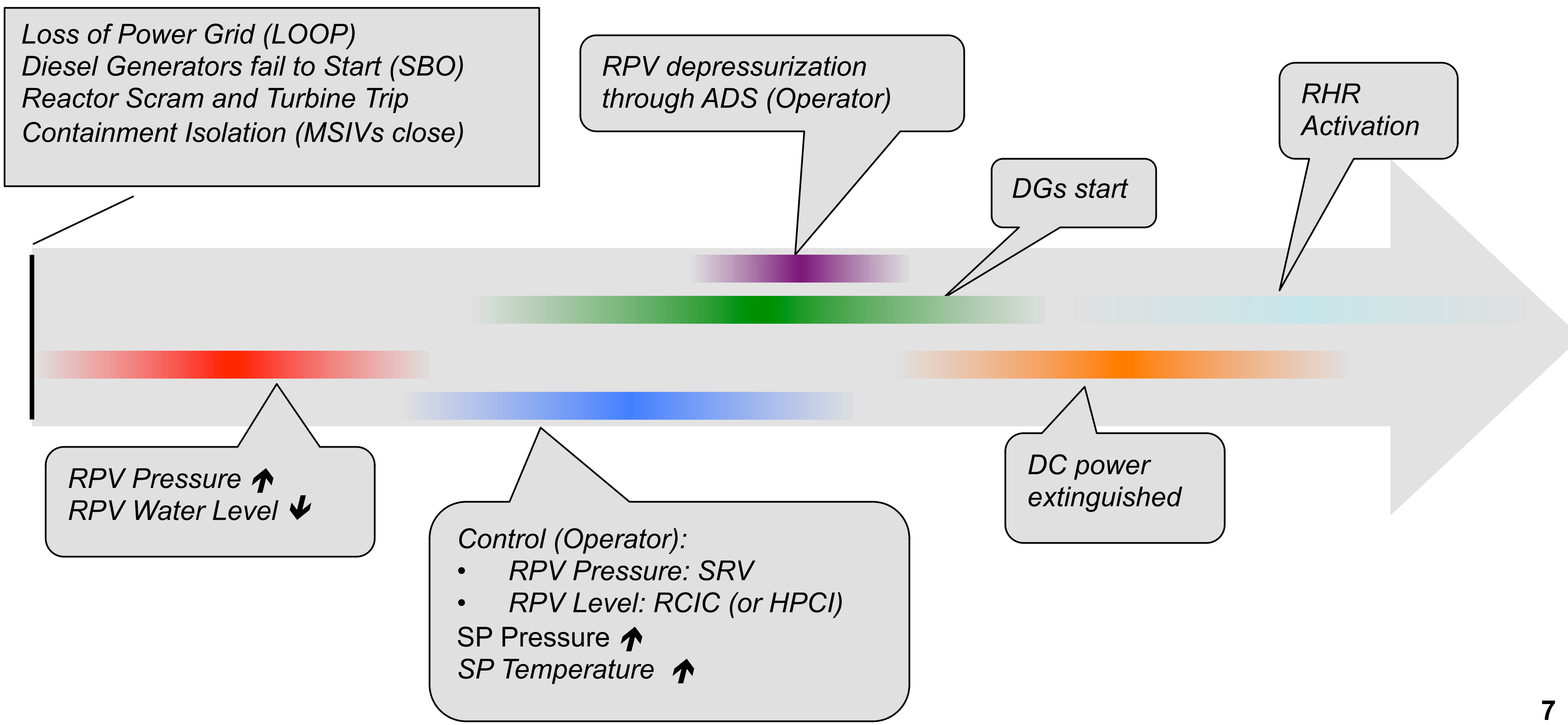
2- ***Model Driven***: *Prediction of system outcome (e.g.,T_{MAX}): surrogate model*





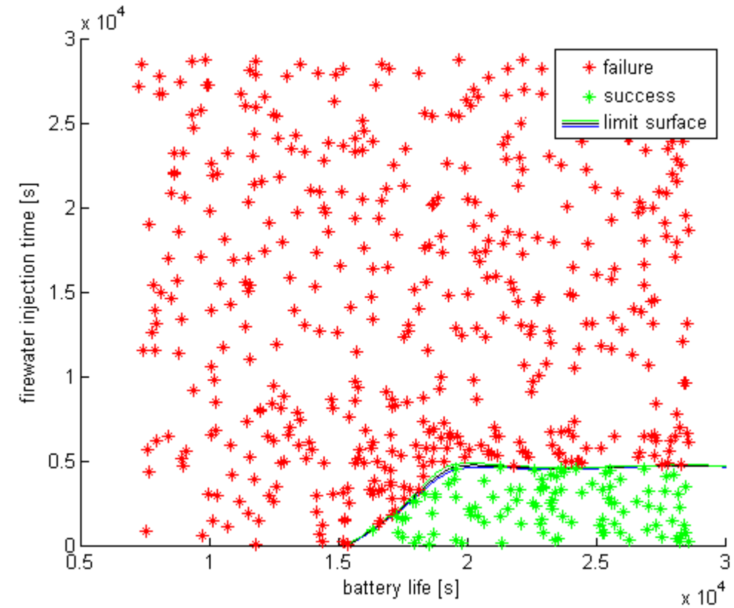
Example of Application: BWR SBO

- **Sequence of events**

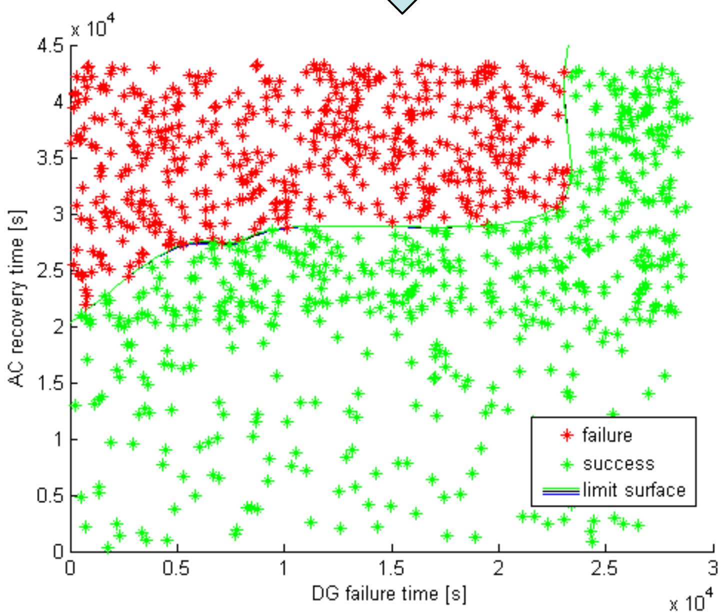


Example of Application: BWR SBO

Fire water injection time vs. battery life



DG failure time vs. AC recovery time



Monte-Carlo sampling: 600 samples

Adaptive sampling: less than 60

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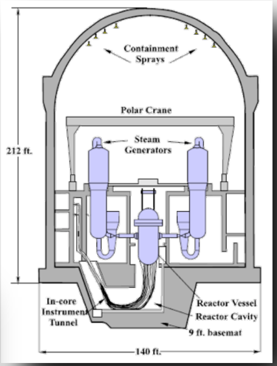

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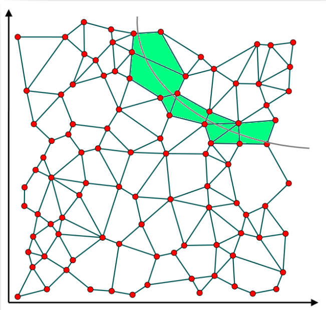
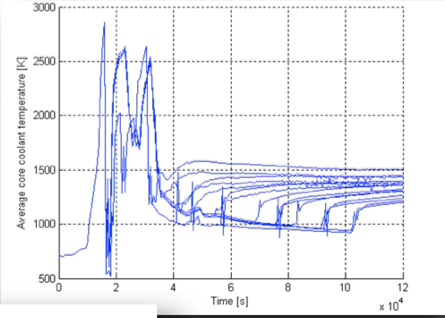
   - *System emulators*



3. *Analyze time dependent data*
   - *Clustering*
   - *Symbolic conversion*



4. *Visualize data*
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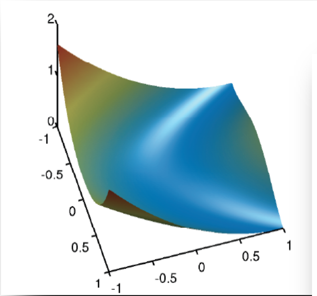
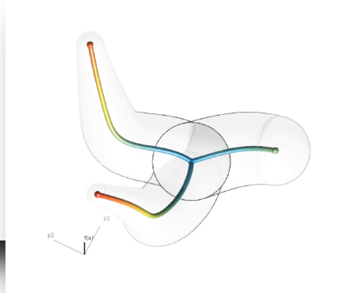
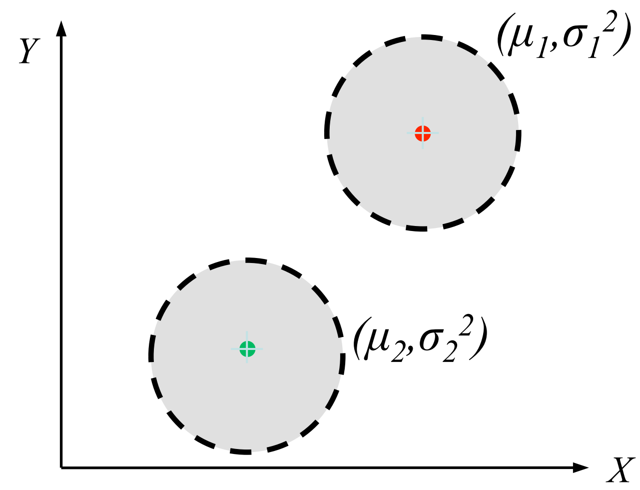
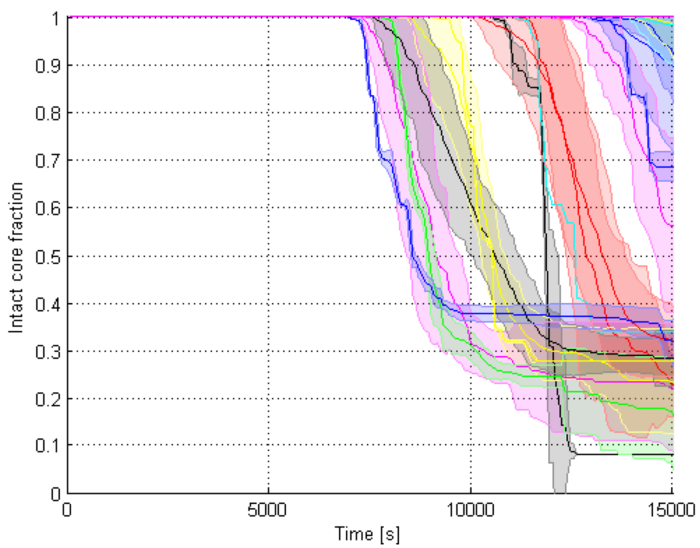




Analyze Time Dependent Data

- *Scope:* *Analyze patterns*
- *Type of data:* *thousands of time dependent transients*
- *Consider the complete time history and not only the end result*
- *Approach:* *cluster data into groups*
  - *Define metric*
  - *Input clustering level*
- *Algorithms:*
  - *Data-centric: K-Means*
  - *Model-Centric: Density gradient based (Mean-Shift)*

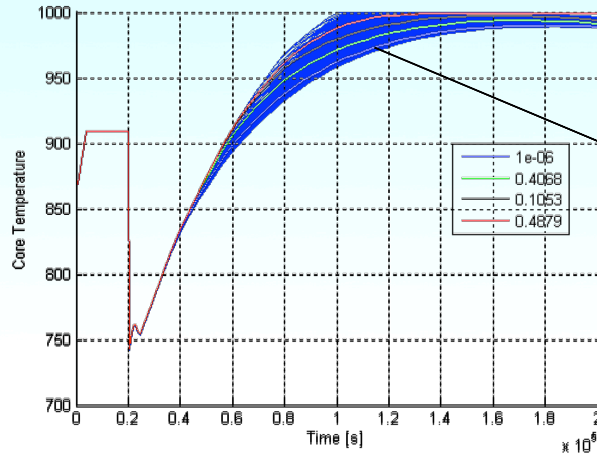


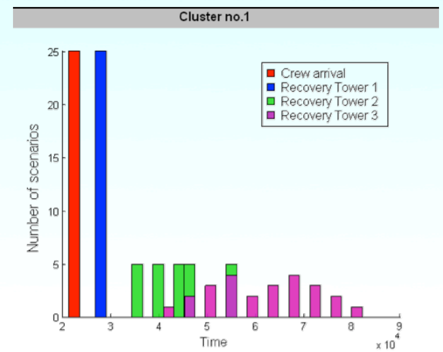


Analyze Time Dependent Data

Identify correlations *between system dynamics and timing of events*

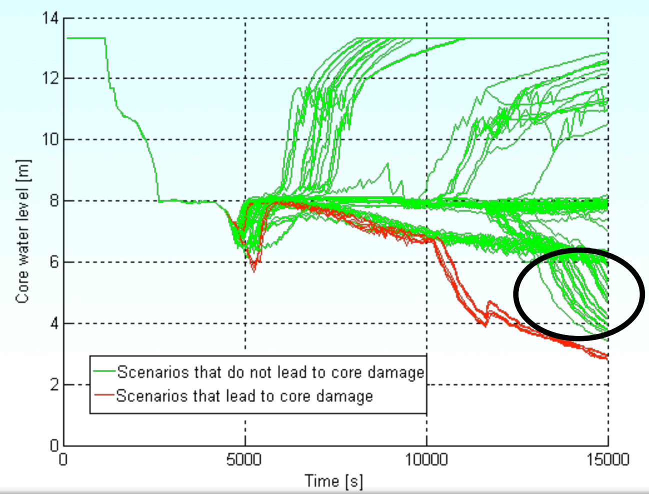
Identify distribution of events for each cluster of scenarios





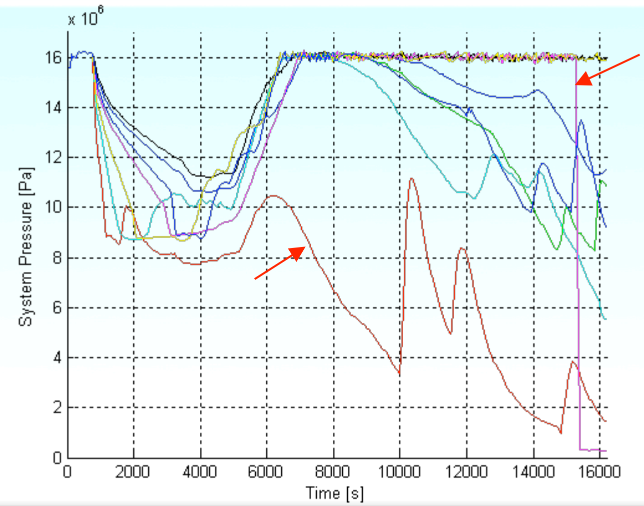
Evaluate “Near Misses” or scenarios that did not lead to CD because mission time ended before reaching CD

Identify clusters containing scenarios that lead to both system failure and system success



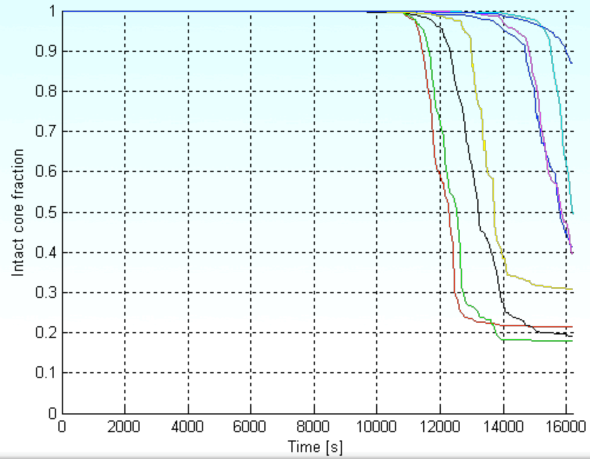
Analyze Time Dependent Data

Identify outliers: “bogus” simulations whose dynamics are different from any other simulation (e.g., out of validity bounds for simulator parameters)

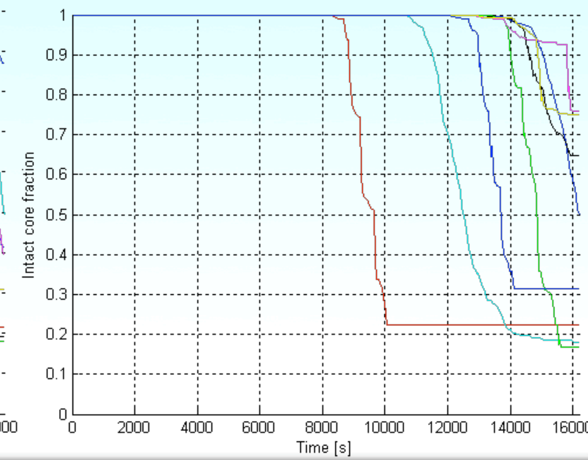


Evaluate system dynamics differences between different sets of analyses (System Design); e.g., different set of system recovery strategies

System Configuration 1



System Configuration 2



Light Water Reactor Sustainability

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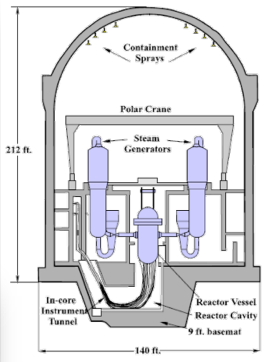
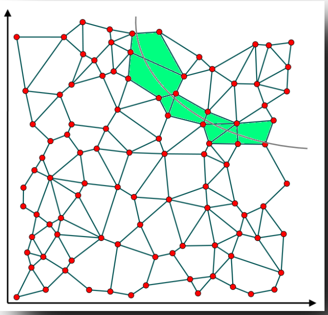
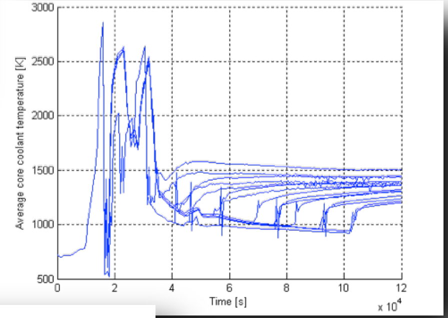
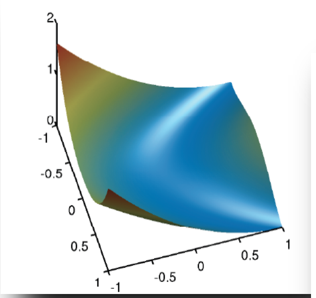
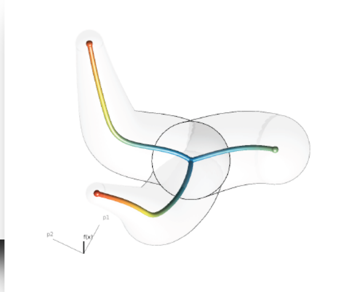










Data Visualization

INL internally funded project with Scientific Computing and Imaging Institute (University of Utah)

Objective: Develop a software tool to visualize high dimensional data as:

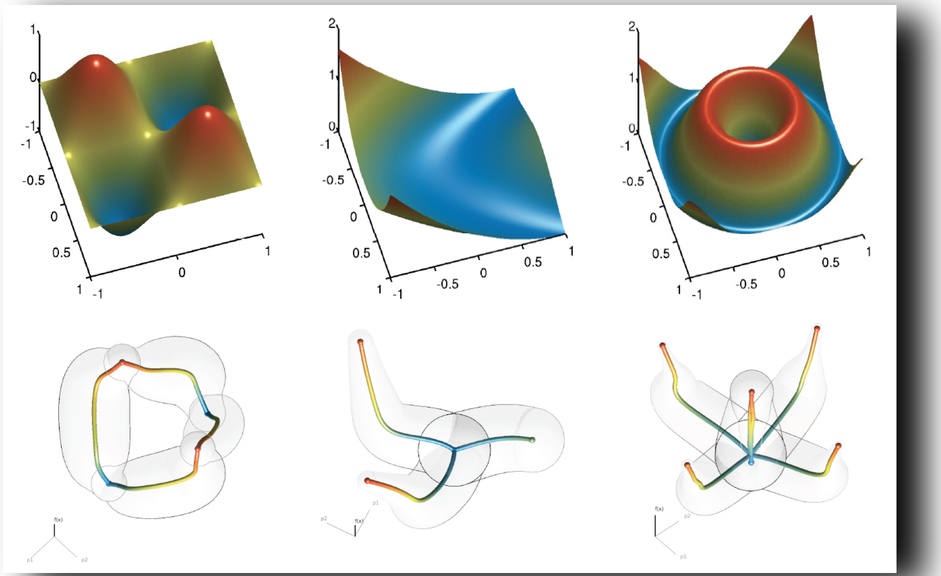
$$\text{system outcome} = f\left(\text{uncertain parameters}\right)$$

Max clad temperature
Max containment pressure

Timing of events
HPI water flow rate
Initial power

Analysis:

- *Exploiting the topological and geometric properties of the domain (Morse-Smale complex)*
- *Building statistical models based on its topological segmentations*
- *Providing interactive visual interfaces to facilitate such explorations.*

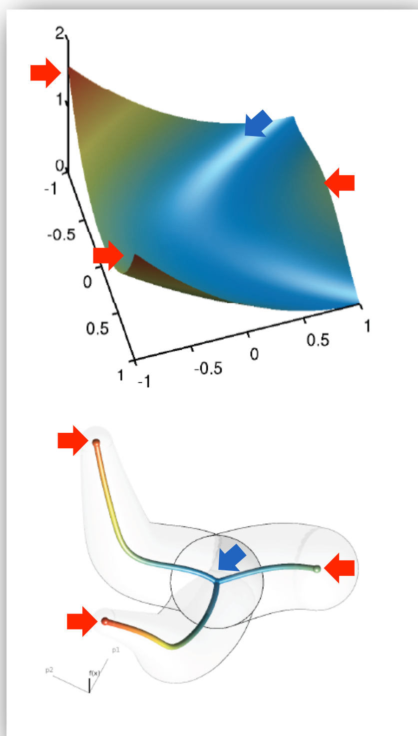


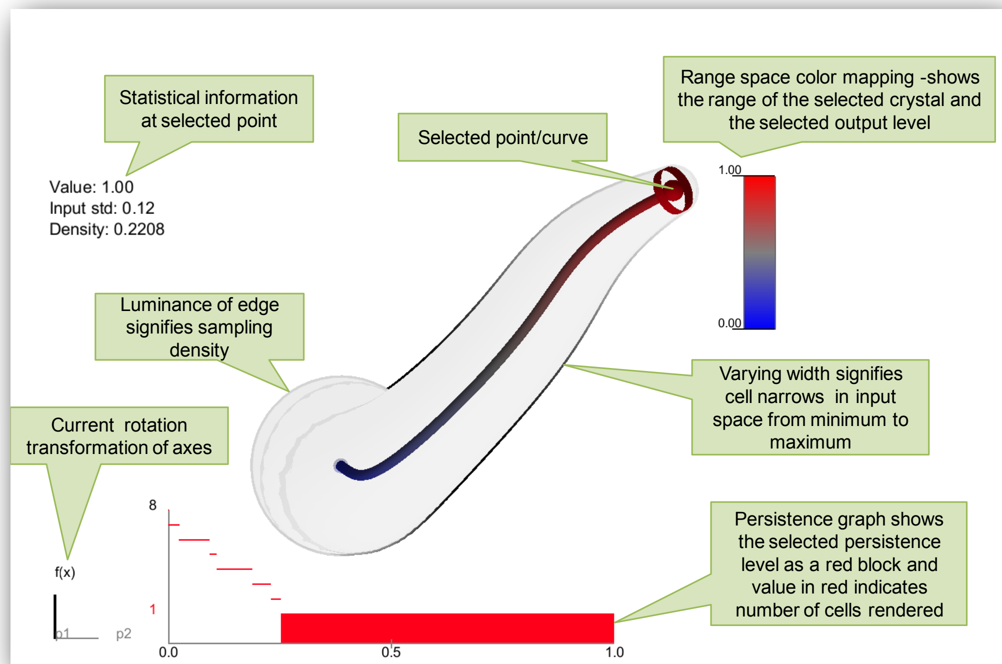
Data Visualization

- **Graphic overview of HDViz to visualize:**

$$system\ outcome\ = f\left(input\ parameters\right)$$

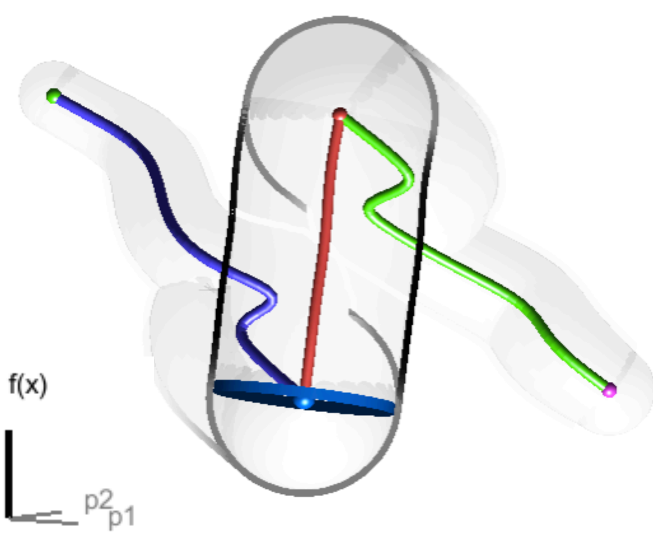
- **Visualize the topological structure of *f* through the connection between its min(s) and max(es)**

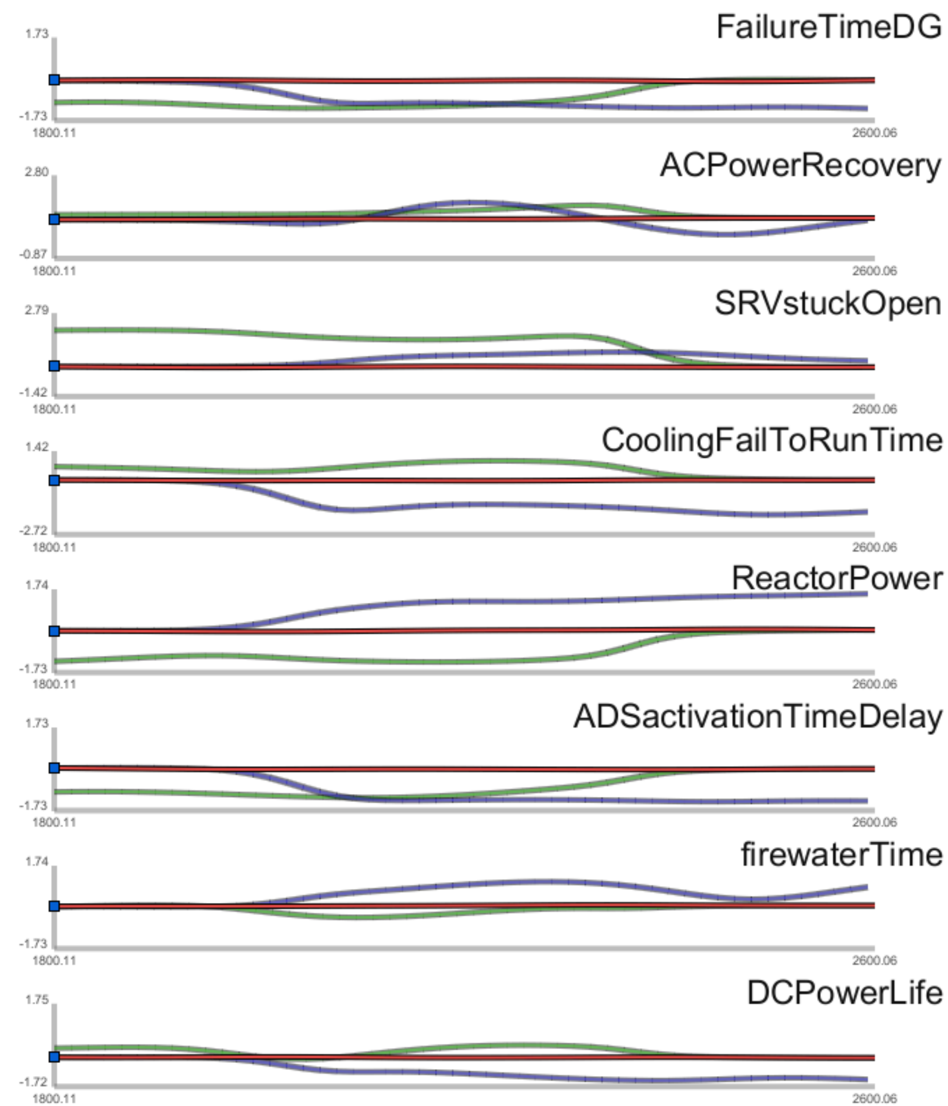




Data Visualization: BWR SBO

- **Example:**
  - 20,000 simulation runs
  - Outcome: Max clad temperature
  - 8 uncertain parameters
  - 2 maxima and 2 minima





Simulation Based PRA: Outline

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